Muon g-2 Status Review
476.2 Accelerators

Mary Convery

L2 Manager

6 April 2016

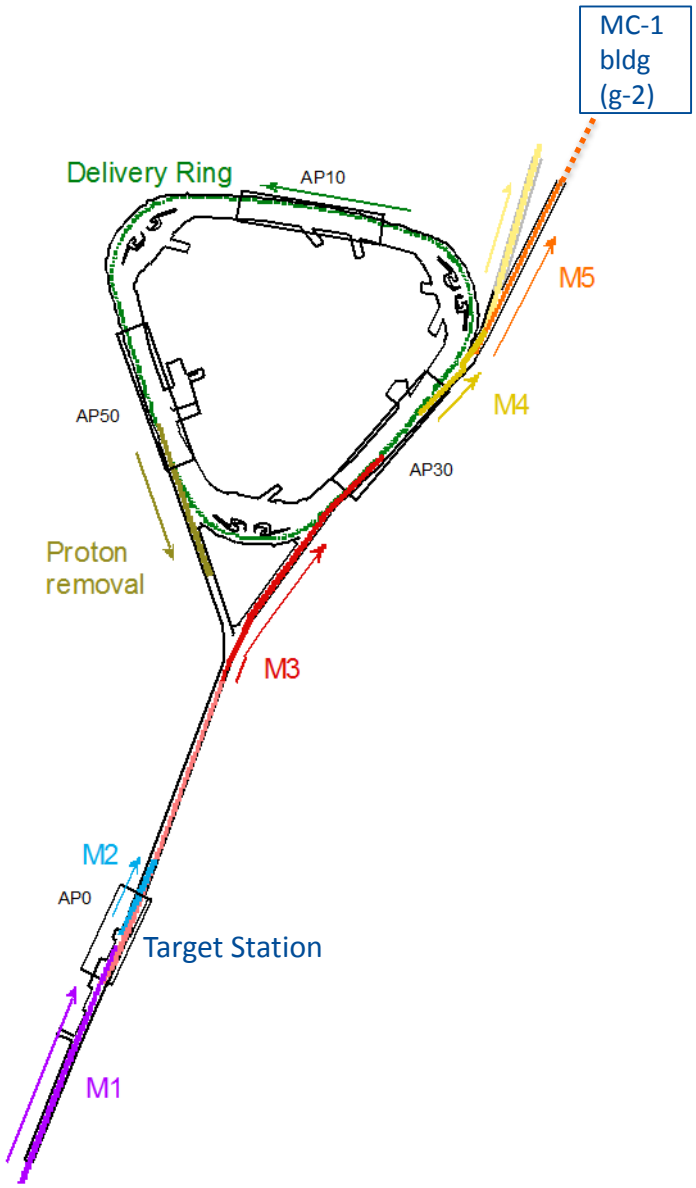
Muon g-2

Outline

- Scope and Organization
- Beam to Muon Campus
  - Proton Improvement Plan
  - Timeline sharing with NOvA
  - Muon Campus Program (AIPs/GPPs)
- g-2 Accelerator Status
  - Target Station
  - Beamlines
  - Controls and Instrumentation
- Earned Value Management
- Summary

Accelerator Scope

- 476.2.2 Target Station
  - Target, focus, momentum-selection, dump
- 476.2.3 Beamlines
  - Final focus on target
  - Pion-decay beamlines (M2/M3)
  - Reconfiguration of extraction region (D30 straight) and extraction from Delivery Ring
  - New external beamline to g-2 storage ring (M4/M5)
- 476.2.4 Controls and Instrumentation
  - Accelerator controls in MC-1 building
  - Safety system for new beamline enclosure and MC-1 building
  - Instrumentation for secondary beam



Accelerator Organization

476.2
Accelerator
M. Convery
Deputy J. Morgan

476.2.1
Project
Management
M. Convery
(FNAL)

476.2.2
Target Station
D. Still
(FNAL)

476.2.3
Beamlines
J. Morgan
(FNAL)

476.2.4
Controls &
Instrumentation
B. Drendel
(FNAL)

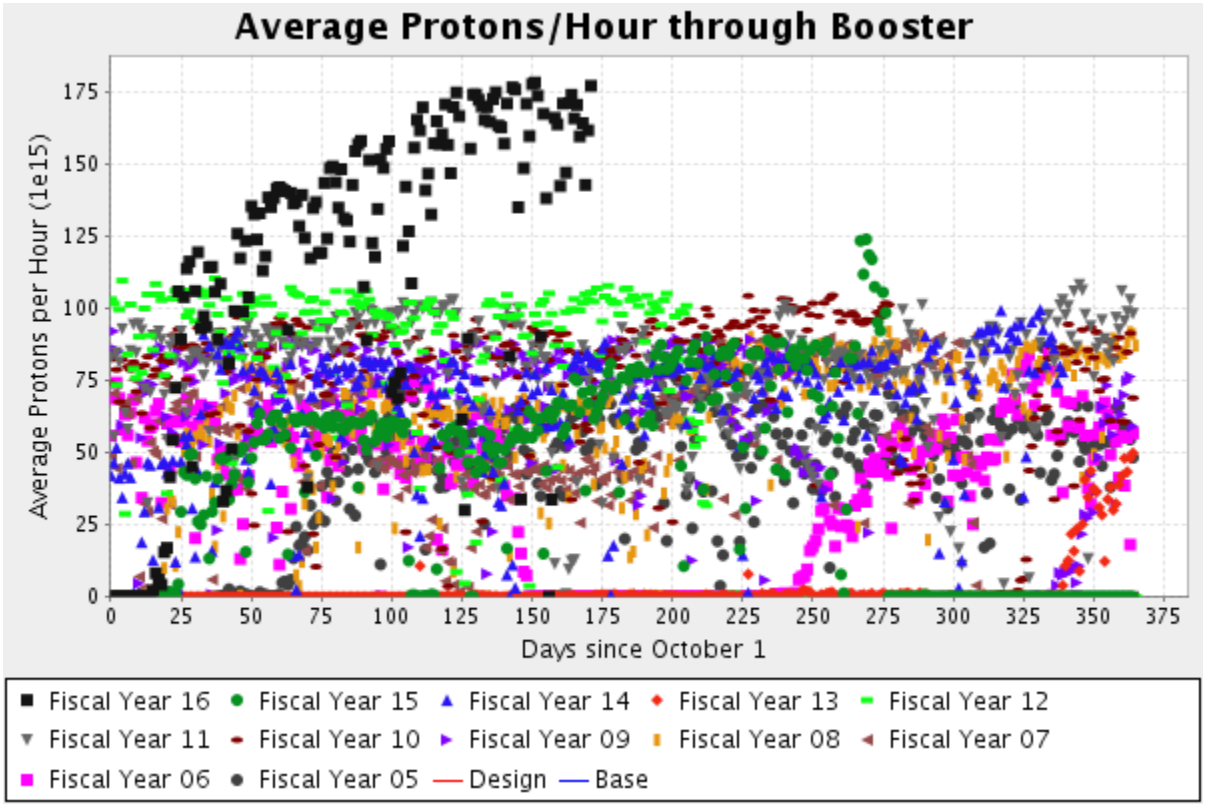
Installation
Coordinator
C. Gattuso
(FNAL)

Beamline
Mechanical
Engineer
C. Ader
(FNAL)

Beam to Muon Campus (not part of g-2 Project)

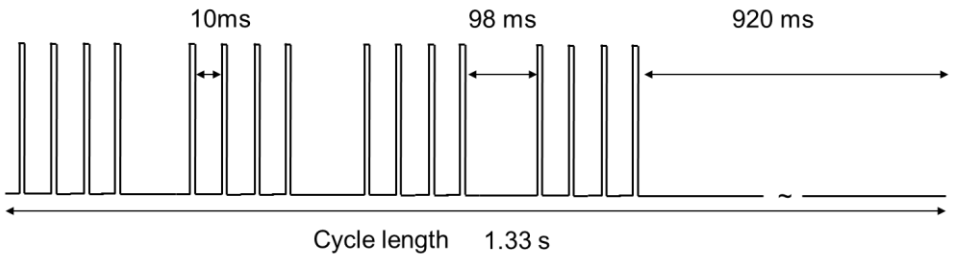
Proton Improvement Plan / Booster 15 Hz

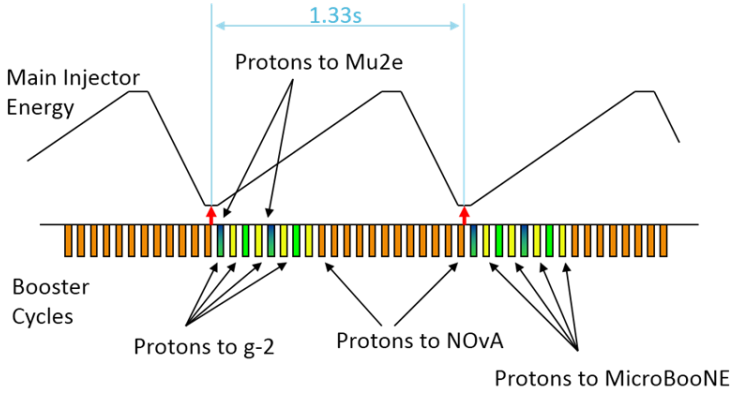
- Capable of 15 Hz Booster beam since June 2015
- Delivering record proton flux
- Enables beam to NuMI (at 700 kW), BNB, and Muon Campus



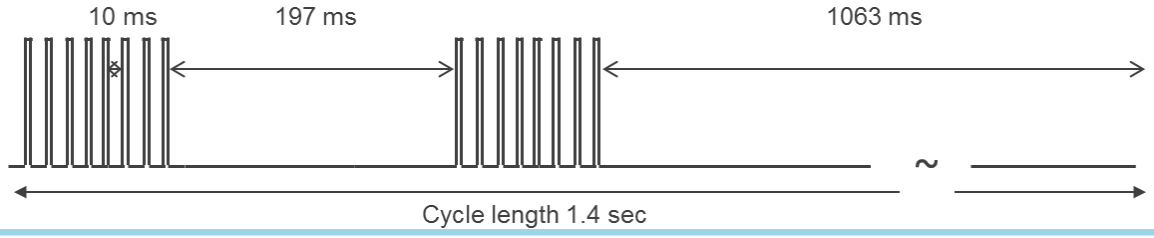
Protons / timeline to g-2

- Design from 2012 which provided 16 bunches to g-2 in a 1.33s NOvA cycle, with bursts of 4 at 100 Hz was found not achievable without impacting beam to NOvA





- Last review showed several new options
- Lab has agreed on default scheme with added Booster cycle to the timeline (21 Booster ticks in a 1.4s NOvA cycle vs 20/1.33s)
  - Provides 95% of what g-2 and NOvA each considered its nominal rate

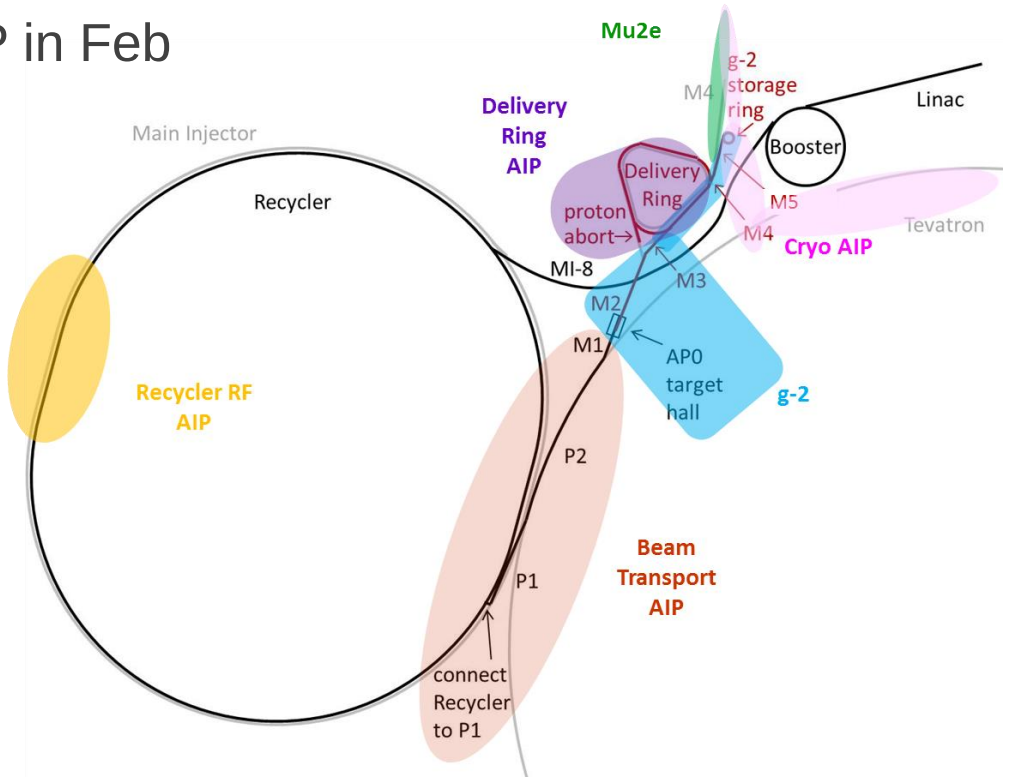


Muon Campus Program

- General Plant Projects substantially complete
  - Roads affected by construction will be resurfaced this summer
- Accelerator Improvement Projects on schedule and sufficient contingency on remaining work
- Had review of Delivery Ring AIP in Feb
- All will be ready in time for g-2

AIP	Total Project Cost	% complete
Delivery Ring AIP	$9.2M	56
Recycler RF AIP	$8.7M	79
Beam Transport AIP	$7.0M	98
Cryo AIP	$9.5M	66*

* cryo work needed for g-2 is 100% complete



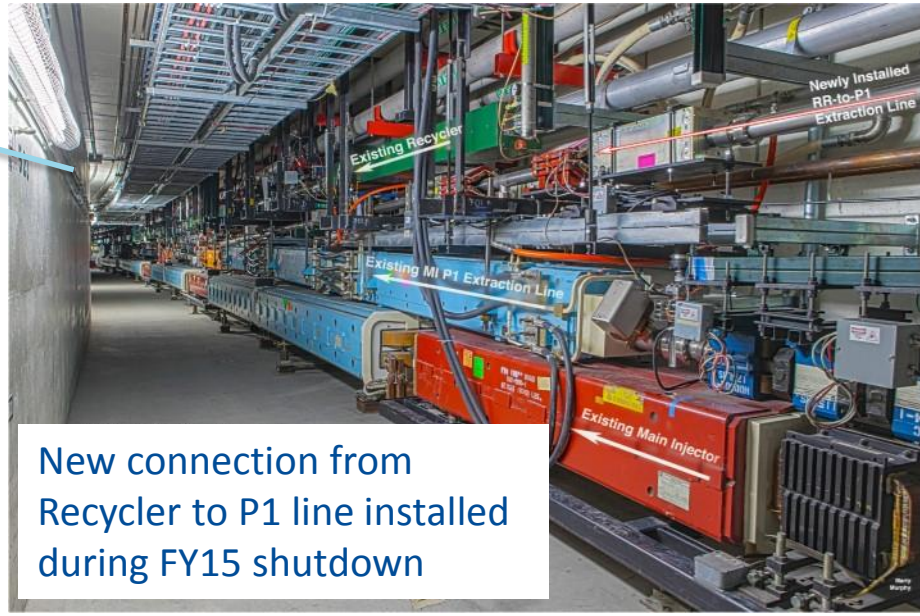
Interfaces between Muon Campus Projects

Milestone Name	Responsibility	Impacts	Forecast / Actual	Needed by
MC-1 Bldg Beneficial Occupancy for Cryo	MC-1 Building GPP	Cryo AIP	1/8/14	as soon as possible
MC-1 Bldg Beneficial Occupancy for g-2 Ring	MC-1 Building GPP	g-2	4/10/14	as soon as possible
End of Circulating Beam Studies	g-2, Mu2e	g-2, Mu2e, Delivery Ring AIP	4/25/14	6/30/14
MC-1 Cryo Room Controls Available	MC-1 Building GPP	Cryo AIP	6/6/14	as soon as possible
Cryo Compressor Cooling Established	MC Infrastructure GPP	Cryo AIP	8/15/14	10/31/14
Cryo g-2 acceptance tests complete	Cryo AIP	lower-level milestone for g-2	10/2/14	as soon as possible
Cryo Ready to Cool g-2	Cryo AIP	g-2	11/30/14	as soon as possible
D30 Straight Section Ready for New Installation	g-2	Delivery Ring AIP	2/5/15	5/17/16
MI-52 Bldg Extension Beneficial Occupancy	MC Infrastructure GPP	Beam Transport AIP	6/10/15	9/30/15
Beamline Enclosure Beneficial Occupancy	Beamline Enclosure GPP	g-2	12/9/15	2/15/16
Beam Transport Complete	Beam Transport AIP	g-2, Mu2e	7/31/16	3/28/17
Recycler RF Complete	Recycler RF AIP	g-2, Mu2e	9/30/16	3/28/17
Delivery Ring Complete	Delivery Ring AIP	g-2, Mu2e	9/30/16	3/28/17
Shield Wall Installation	g-2	Mu2e	1/5/17	before g-2 running
Cryo: Mu2e Distribution Box Cold	Cryo AIP	Mu2e	7/15/17	9/15/17

- Remaining interface milestones which impact g-2 only affect beam delivery and are required to be ready by the time we are ready to start commissioning beam to g-2 (end of March 2017)

Muon Campus Recycler Modifications

New RF cavities ready to install in FY16 shutdown



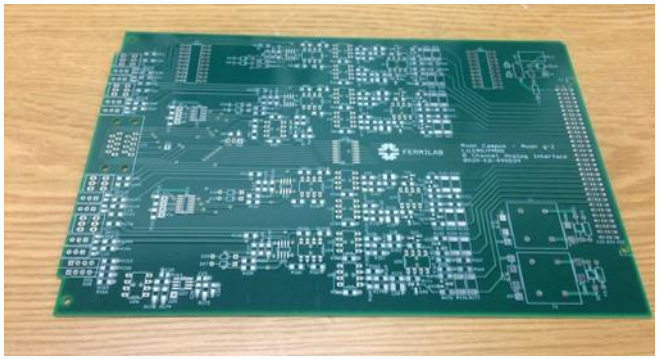
New connection from Recycler to P1 line installed during FY15 shutdown

M4/M5 Beamline Enclosure

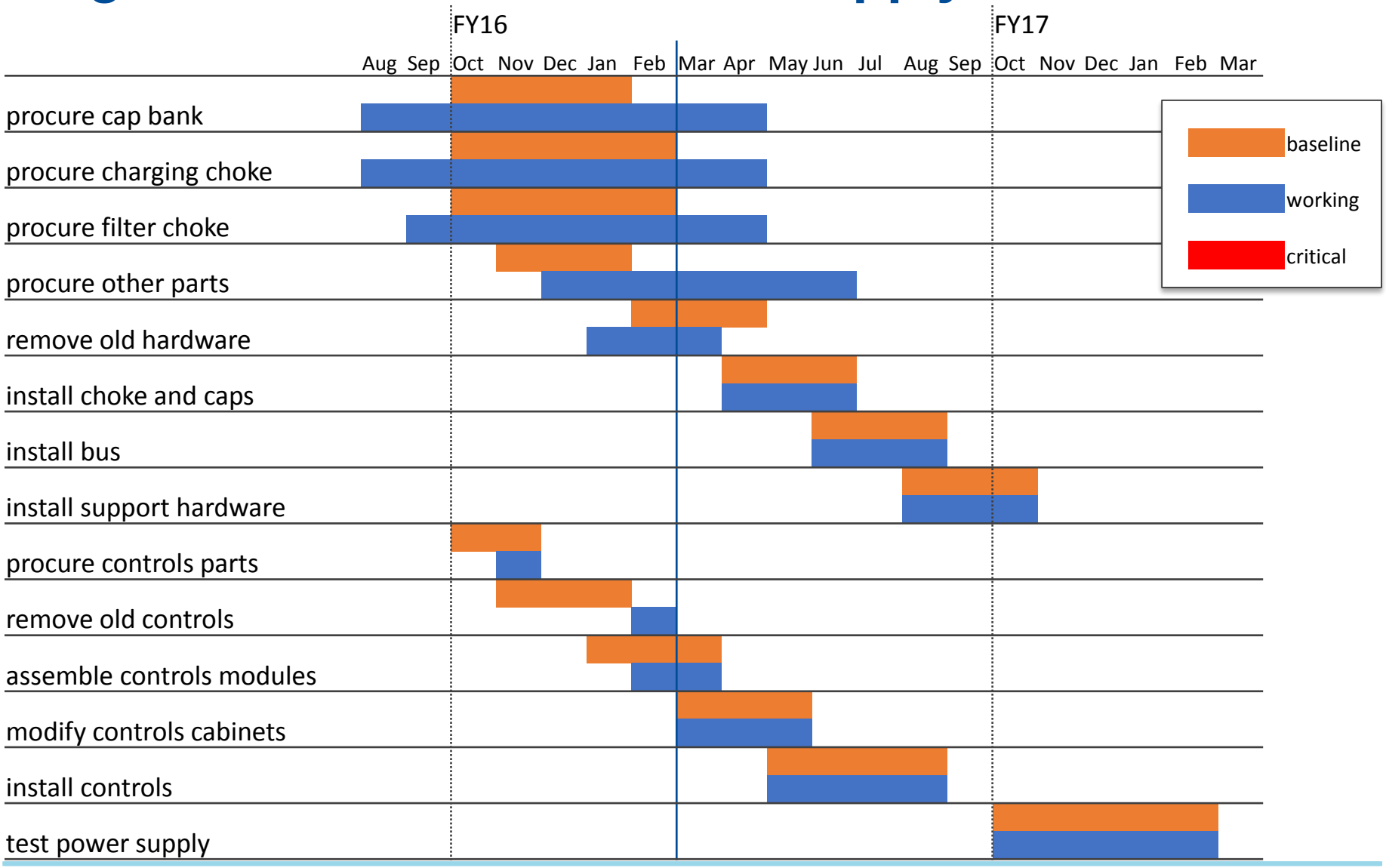
g-2 Target Station

Target Station Pulsed Power Supplies

- Existing supplies disassembled
- Long-lead parts ordered and expected this month (cap bank, chokes)
  - Engineer visiting vendor to confirm specifications have been met
- Assembling controls modules



Target Station Pulsed Power Supply Schedule

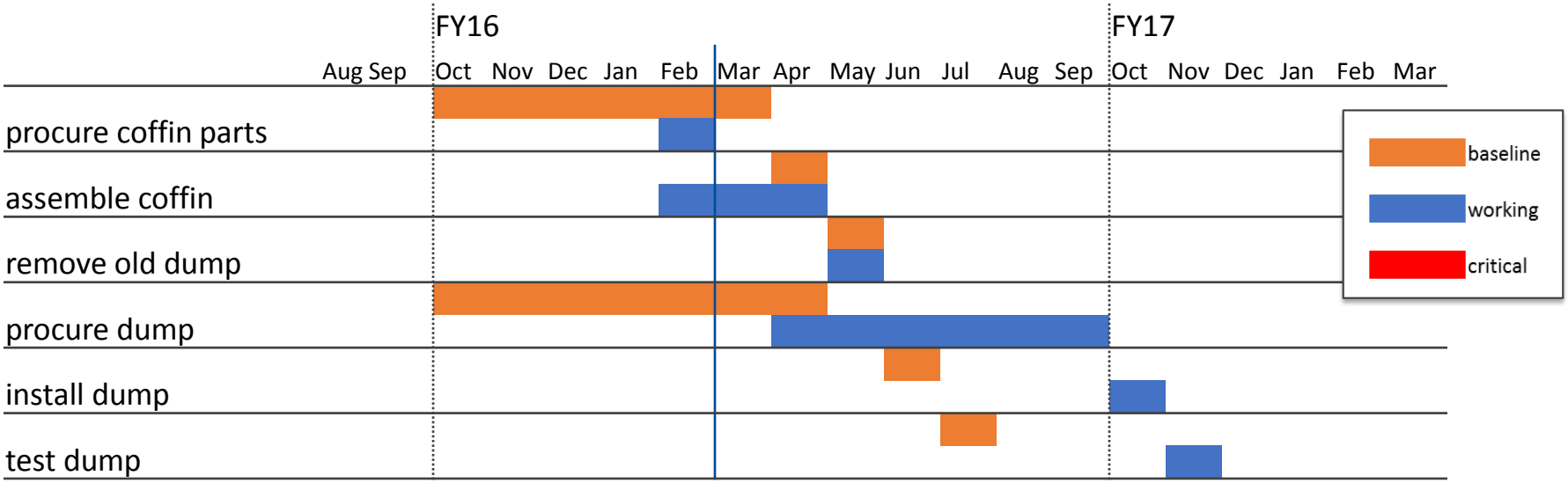


Target Station Dump

- Coffin assembled, will be painted, then ready for dump removal

- Would like to remove existing dump as soon as possible to reduce schedule risk
- Coordinating with commissioning beam from Recycler to Target Station – prefer not to run beam to current dump before removal
- Dump procurement in progress

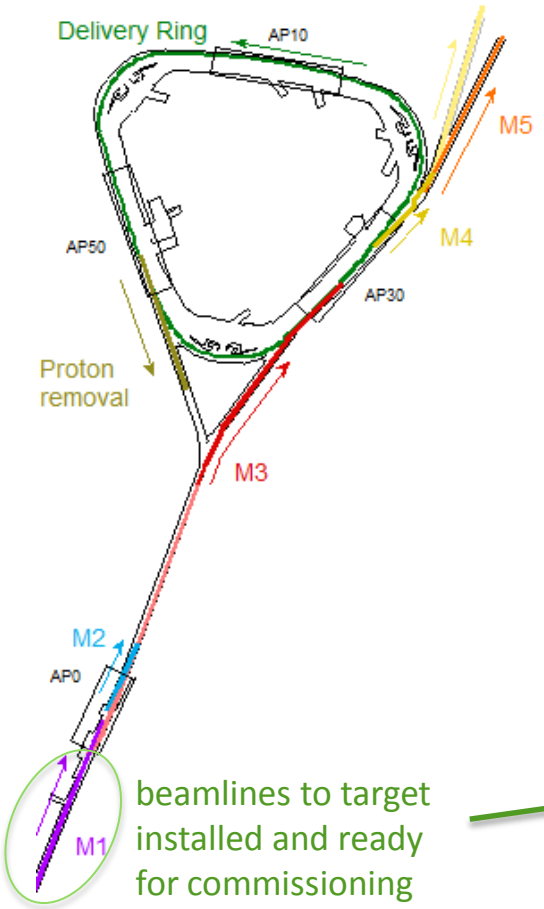
Target Station Dump Schedule



- As far as schedule risk, more concern about removing existing dump than installing new dump
- Working schedule supports commissioning beam from Recycler to target station dump after the summer shutdown

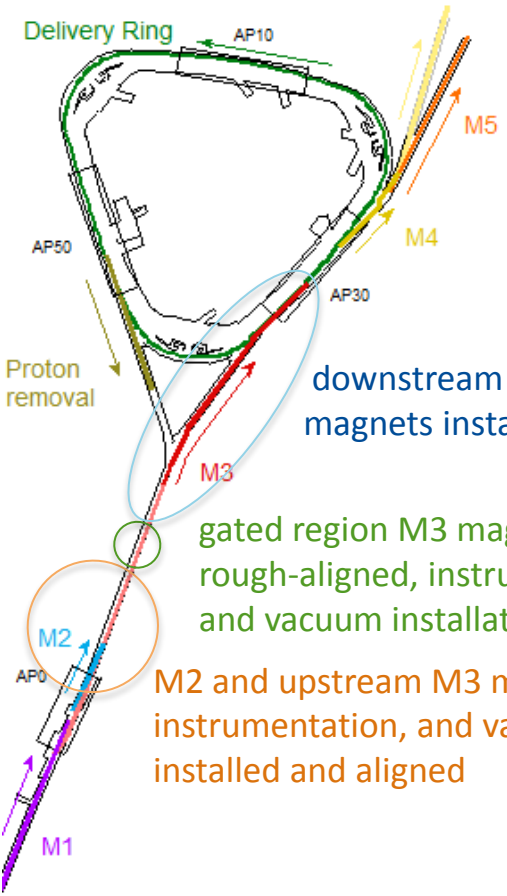
g-2 Beamlines

Beamline Construction – M1 Final Focus on Target



beamlines to target installed and ready for commissioning

Beamline Construction – M2/M3 Lines

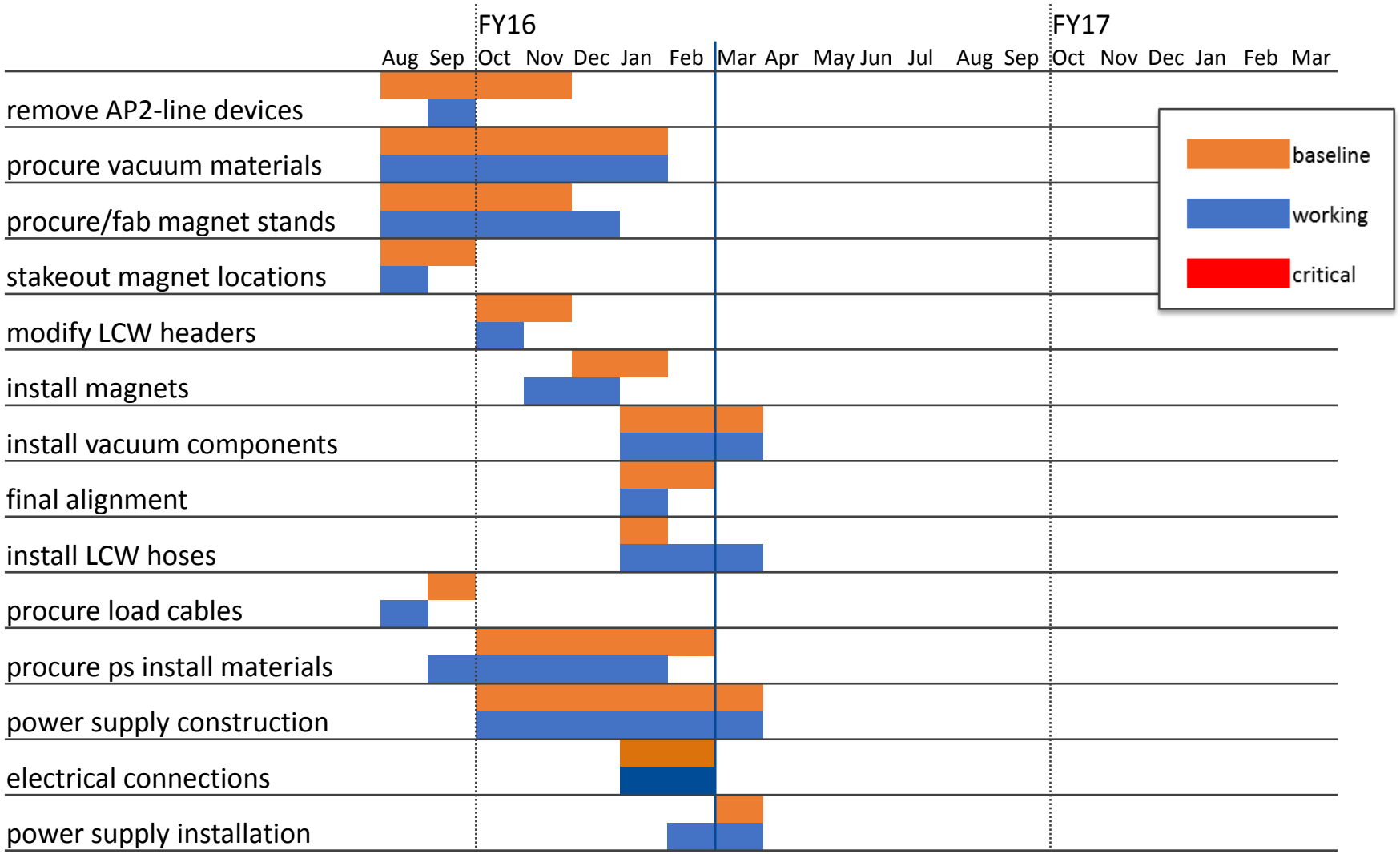


downstream M3 magnets installed

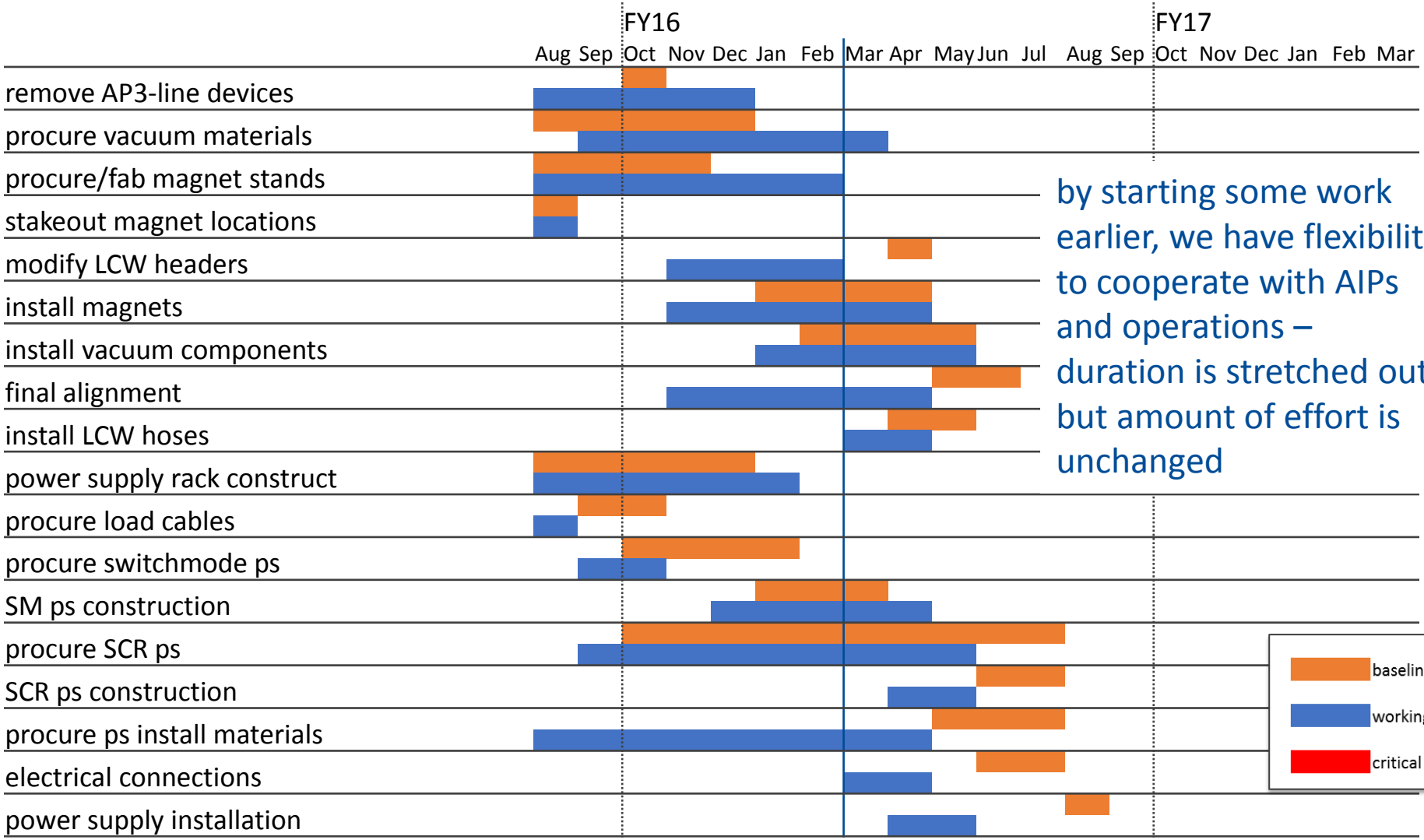
gated region M3 magnets installed and rough-aligned, instrumentation installed, and vacuum installation in progress

M2 and upstream M3 magnets, instrumentation, and vacuum installed and aligned

M2-Line Schedule

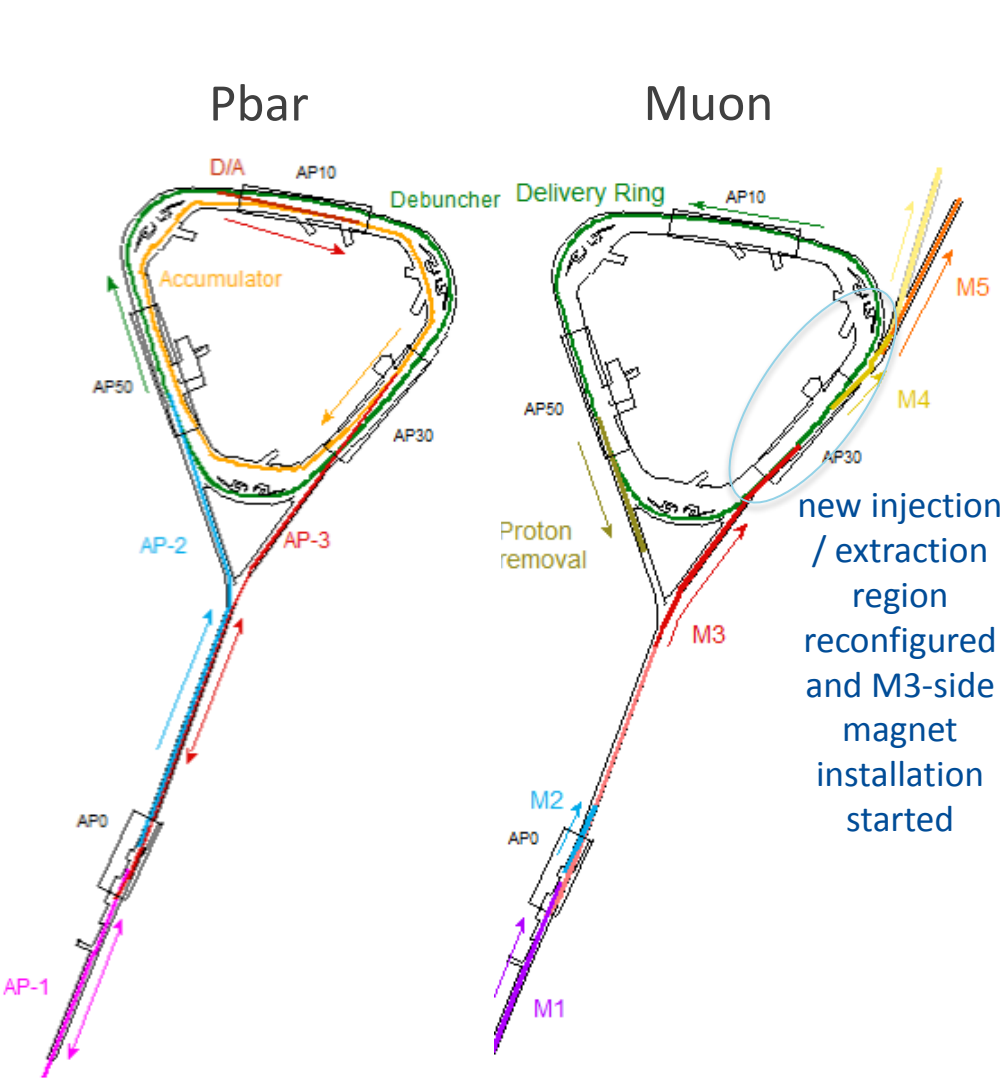


M3-Line Schedule



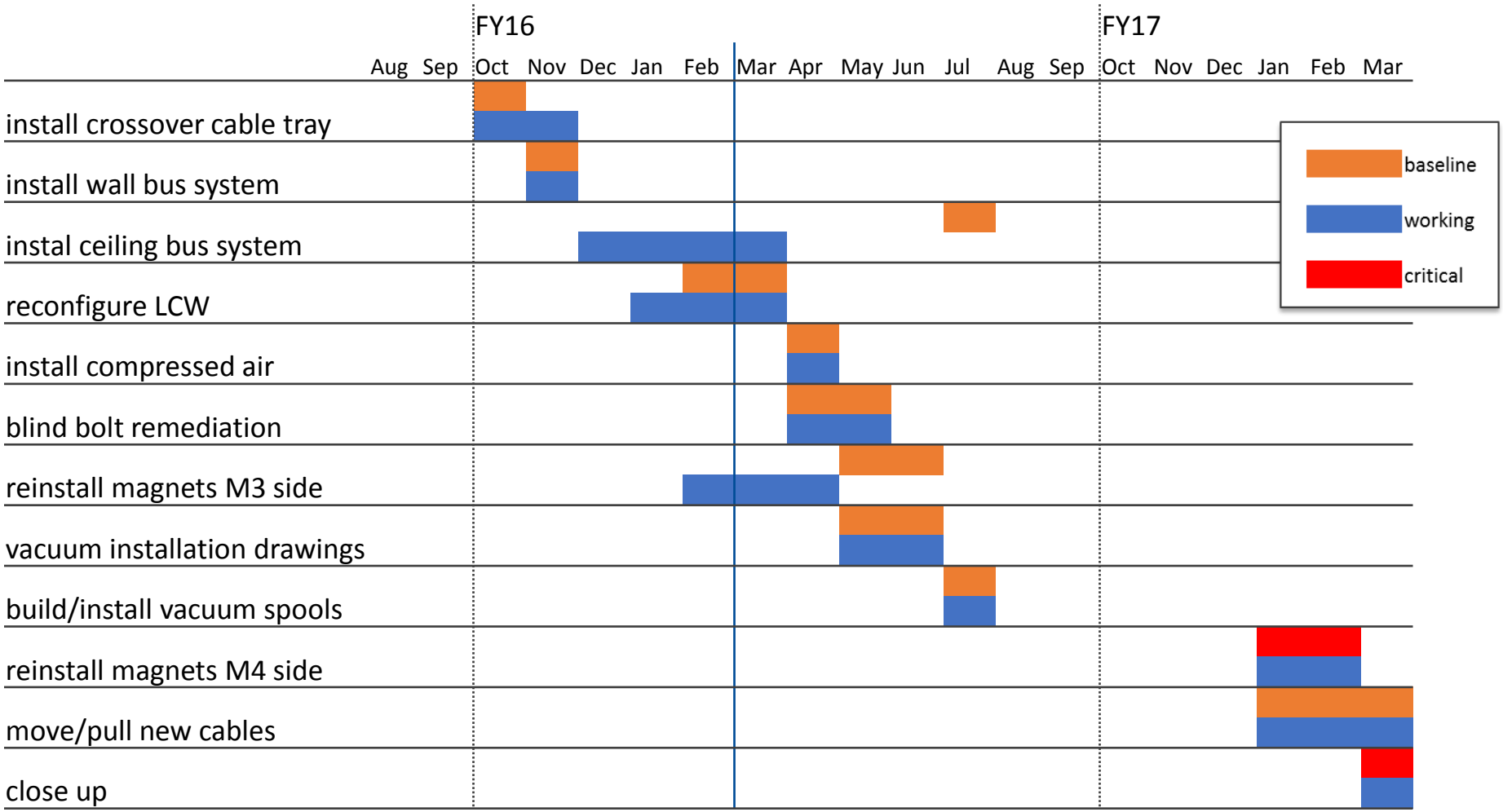
by starting some work earlier, we have flexibility to cooperate with AIPs and operations – duration is stretched out but amount of effort is unchanged

Beamline Construction – D30 Straight



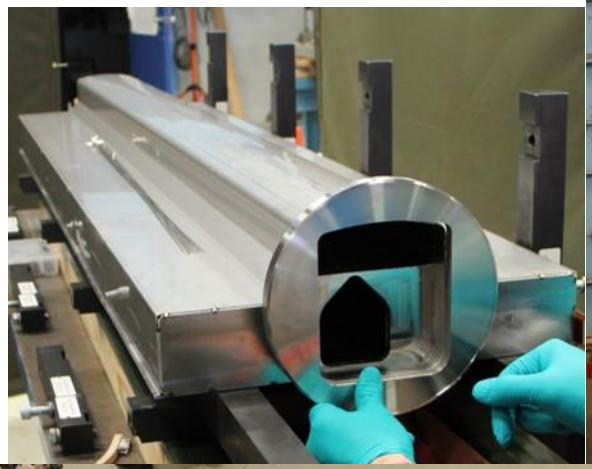
new injection / extraction region reconfigured and M3-side magnet installation started

D30 Straight Schedule



DR Extraction Magnets

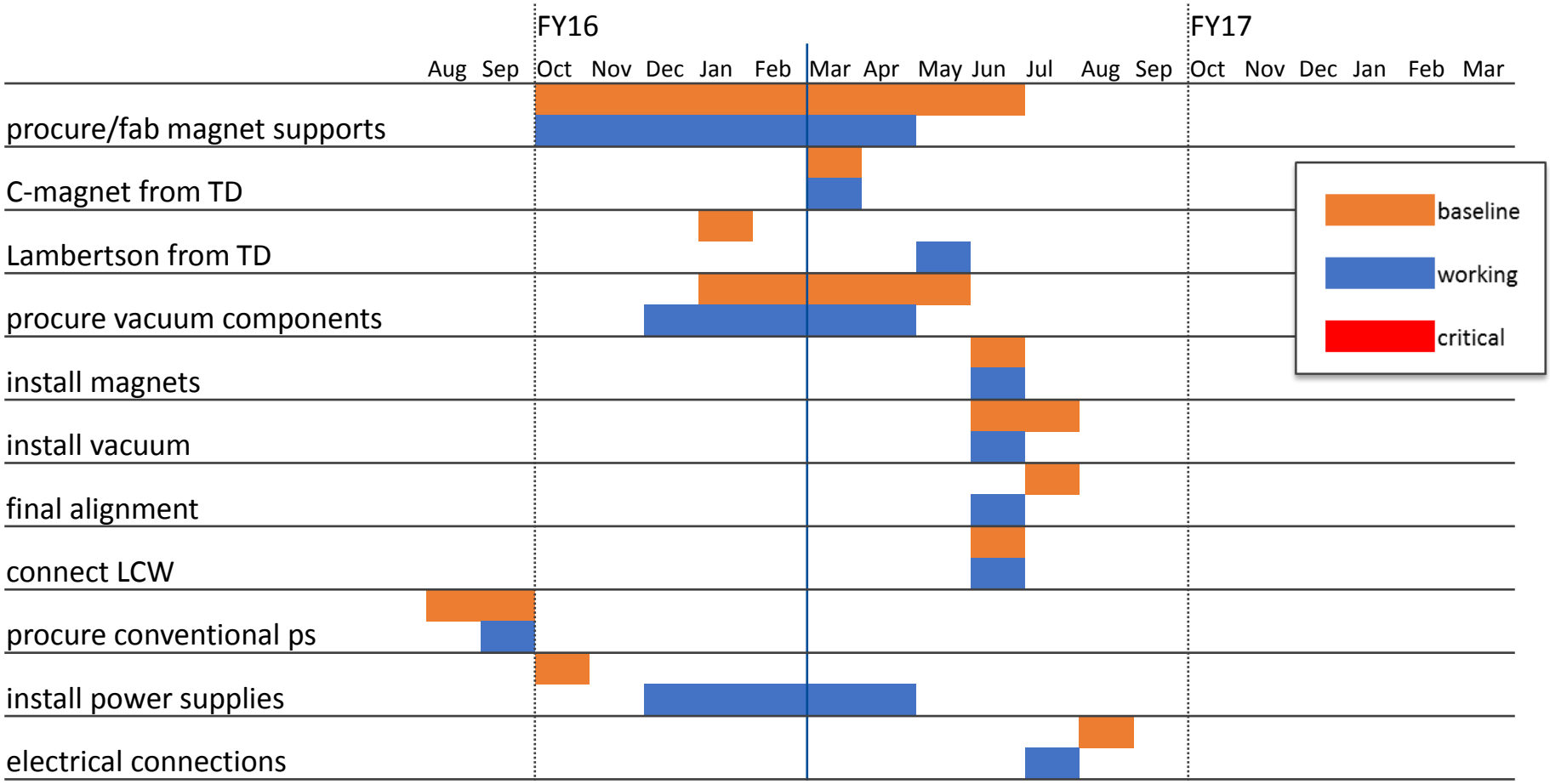
- Magnet production by Technical Division behind schedule but magnets will be ready in time for original baseline installation date
- C-magnet has been tested successfully
- Lambertson baking in progress



C-magnet at test facility

Lambertson bake-out

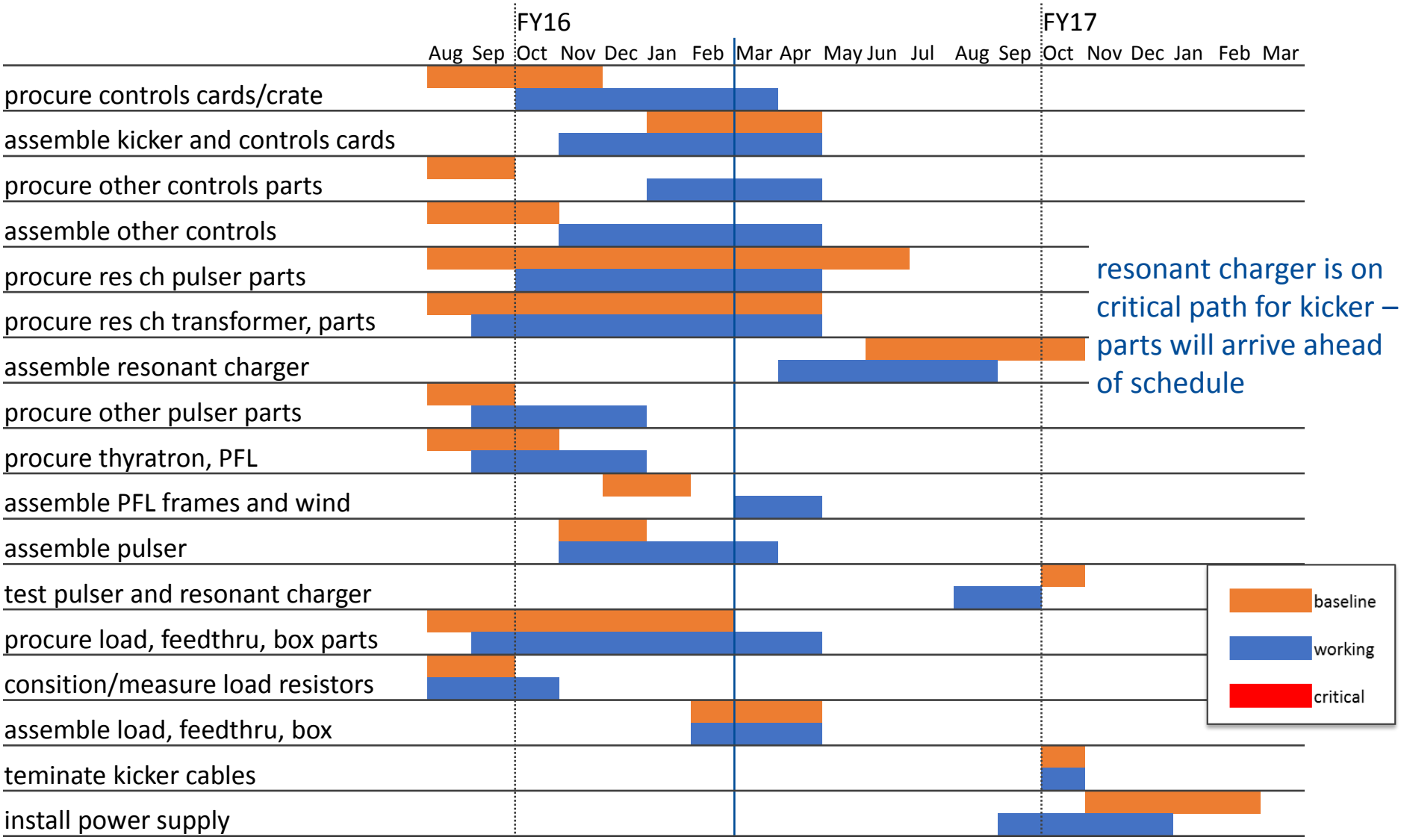
DR Extraction Mechanical/Magnet Schedule



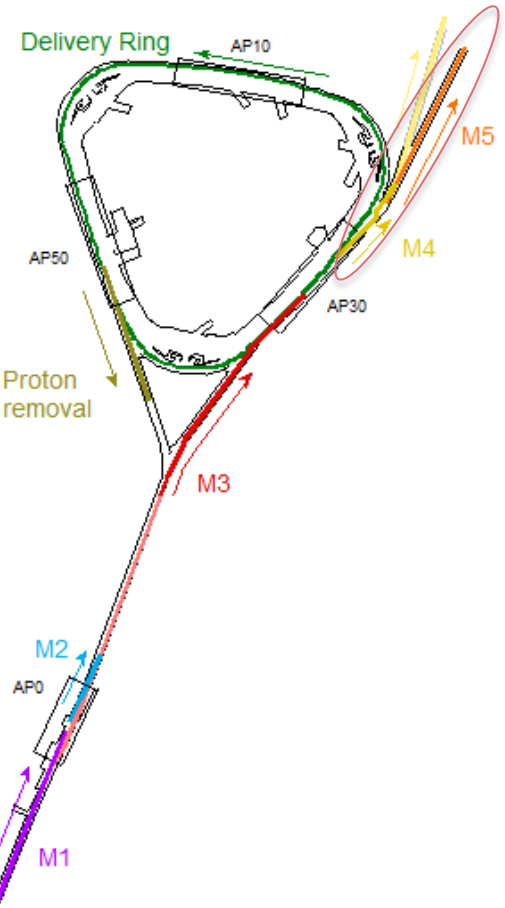
DR Extraction Kicker Power Supply

- Pulser and thyratron assembly almost complete
- Pulser controls assembly in progress
- Load assembly in progress but expertise not available and steep learning curve, need 12 loads for Muon Campus
- Resonant charging pulser parts received
- Resonant transformer and tank
  - To reduce schedule risk, instead of buying complete assembly, bought transformer, high voltage bushings and voltage monitors (received) and having tank fabricated separately
- Pulse forming line (PFL)
  - Cable and frame received, Technical Division is winding (same resources as magnet production)

Extraction Kicker Power Supply Schedule

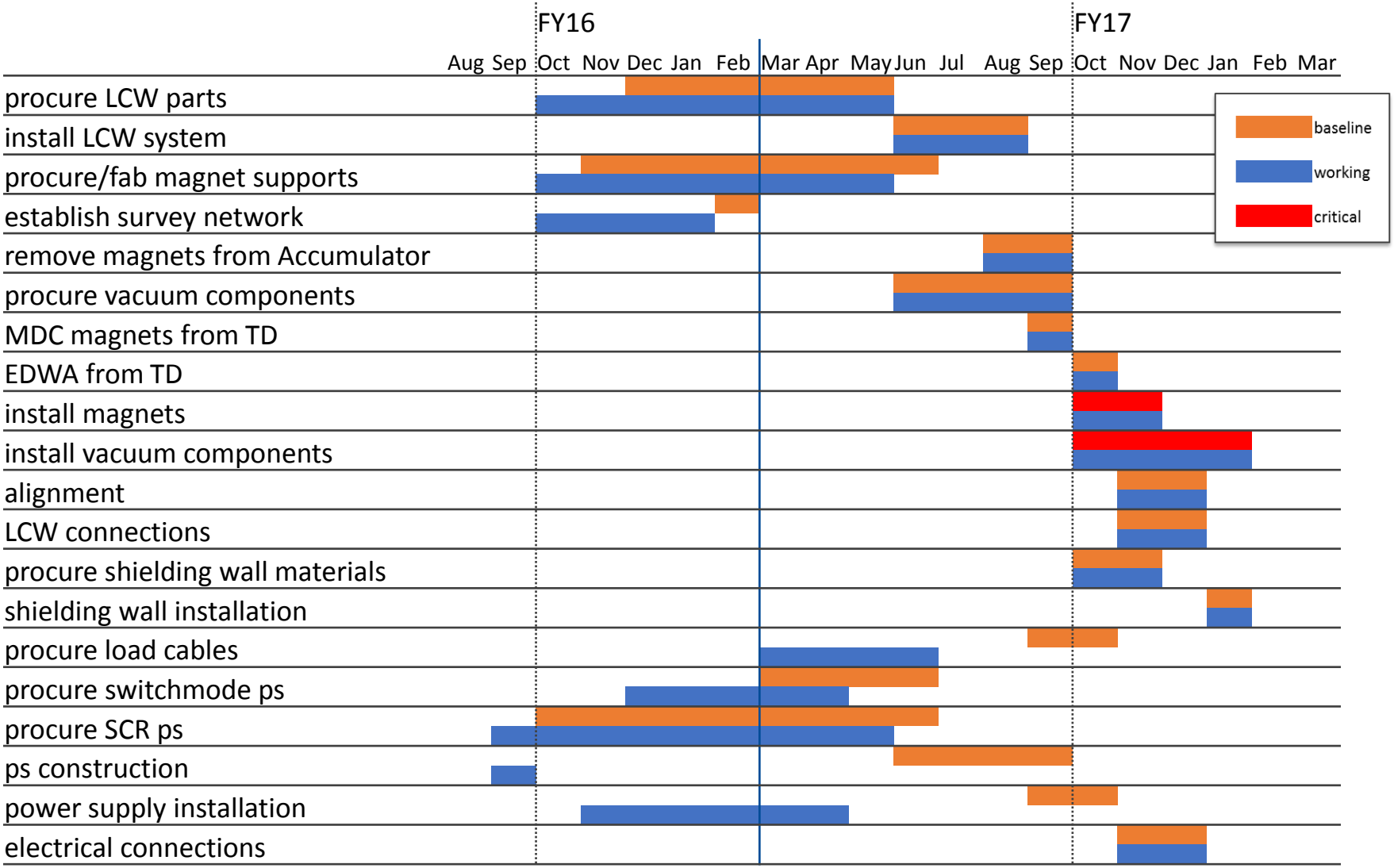


Beamline Construction – M4/M5 Lines



- Preparing for installation of cooling water pipes
- Procuring magnet stands
- Magnets removed from Accumulator and staged
- Baseline schedule assumes resources will not be available for installation during the summer shutdown
  - Will use as fill-in work for riggers and electricians
- Quadrupoles in MC-1 building installed and preparing to power for ring shimming

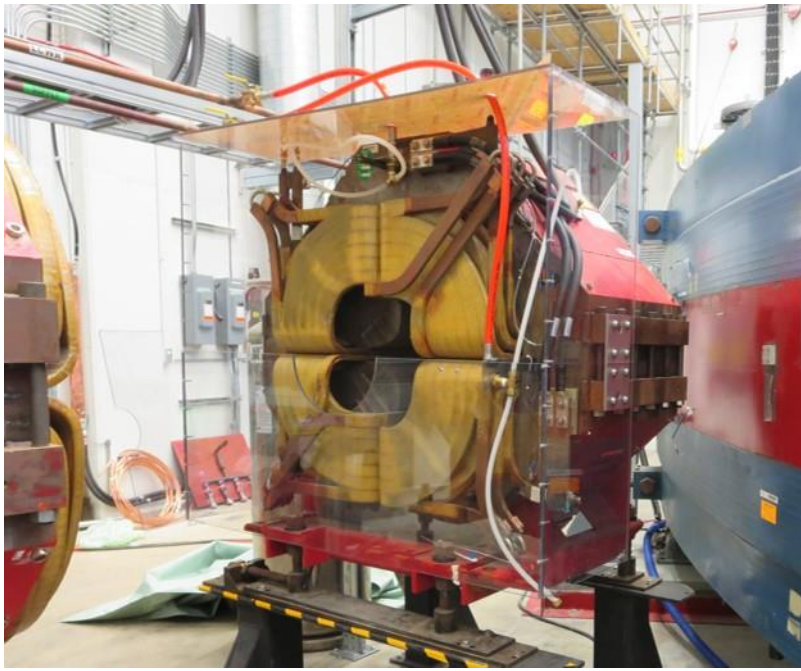
M4/M5-Line Schedule



Beamline Power Supplies

- Controls and regulation components assembled, racks constructed
- All power supplies ordered and delivery expected by June

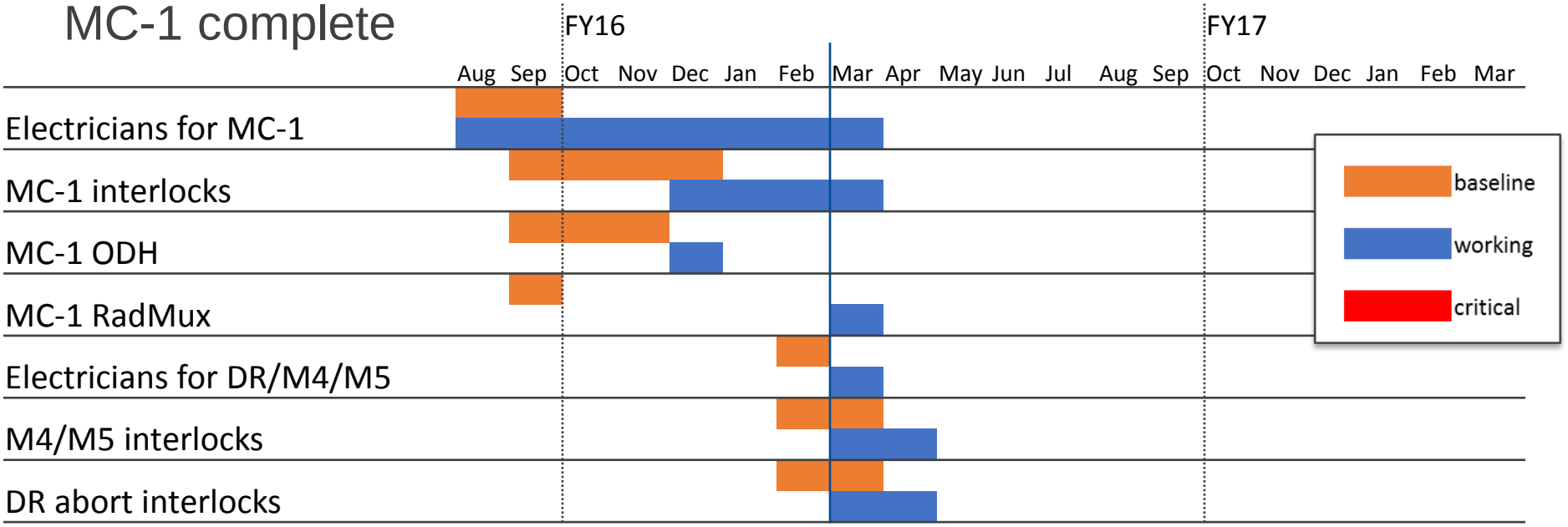
MC-1 power supply room


preparing to power beamline quads in MC-1 for ring shimming

g-2 Accelerator Controls and Instrumentation

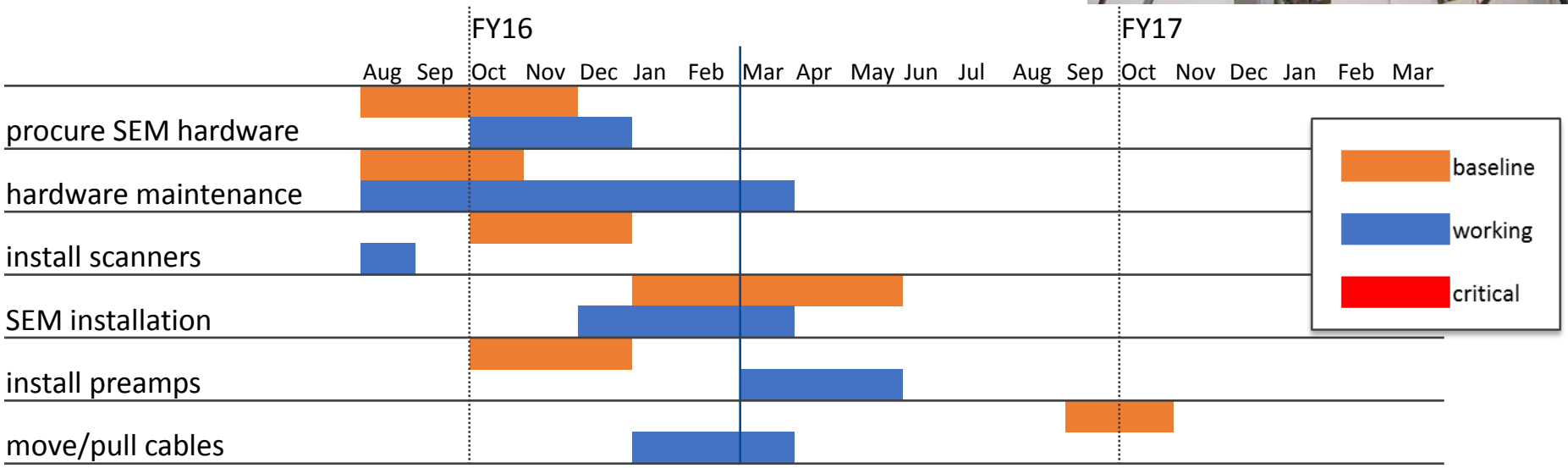
Controls and Safety Systems

- Controls complete
- MC-1 safety system interlocks behind schedule due to coordination with Ring work in MC-1 bldg
  - MC-1 safety systems 90% complete
  - Not needed for ring shimming
- Will install Delivery Ring/M4/M5 interlocks after MC-1 complete



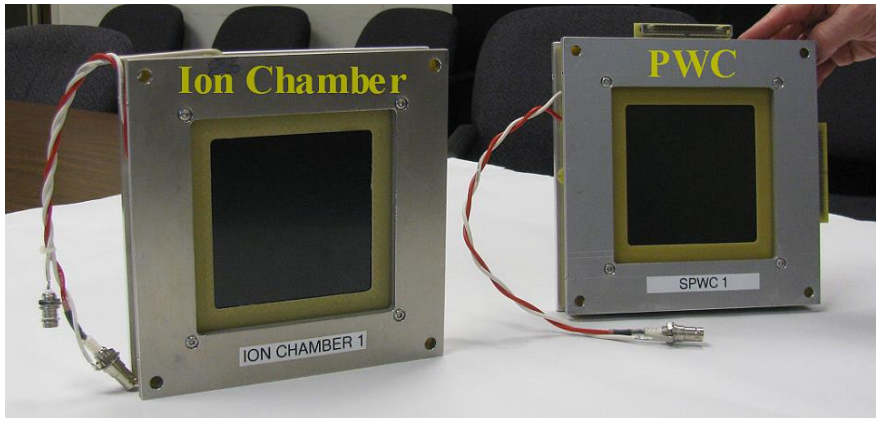
Secondary Emission Monitors

- SEMs measure beam profile in M2/M3/DR
- 75% installed, remaining 25% ready to install
- Readout electronics assembled and installed/ready to install
- Cable pulls in progress



Proportional Wire Chambers and Ion Chambers

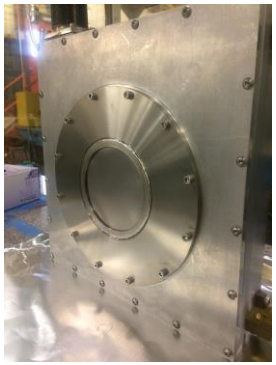
- Ion Chambers measure beam intensity in all beamlines
- PWCs measure beam profile in DR/M4/M5
- Similar design, both are installed inside anti-vacuum chambers inside bayonet cans
- Readout electronics complete
- PWC and IC assembly in progress



- Bayonet can and anti-vacuum chamber modifications behind schedule and over budget due to prototyping
  - Didn't change baseline plan until had solution known to work
  - Don't expect further overruns

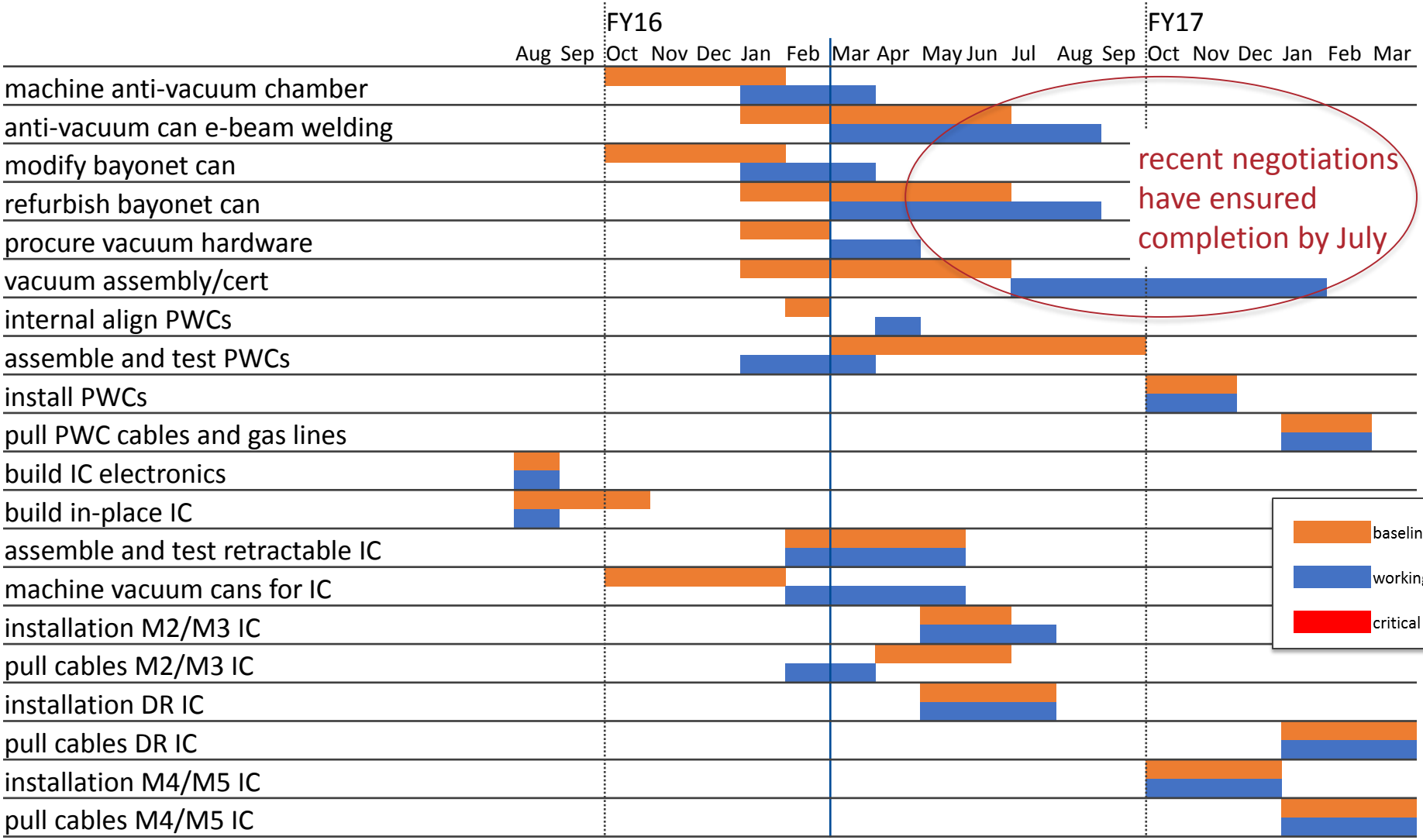
Bayonet Cans and Anti-vacuum Chambers

- Electron-beam welding for first unit successfully completed without issues
  - Using titanium flange



- Ion chamber is installed inside of first ebeam-welded anti-vacuum box, which was installed inside a bayonet can
- Unit passed two-stage vacuum certification and is ready to install in M2 line

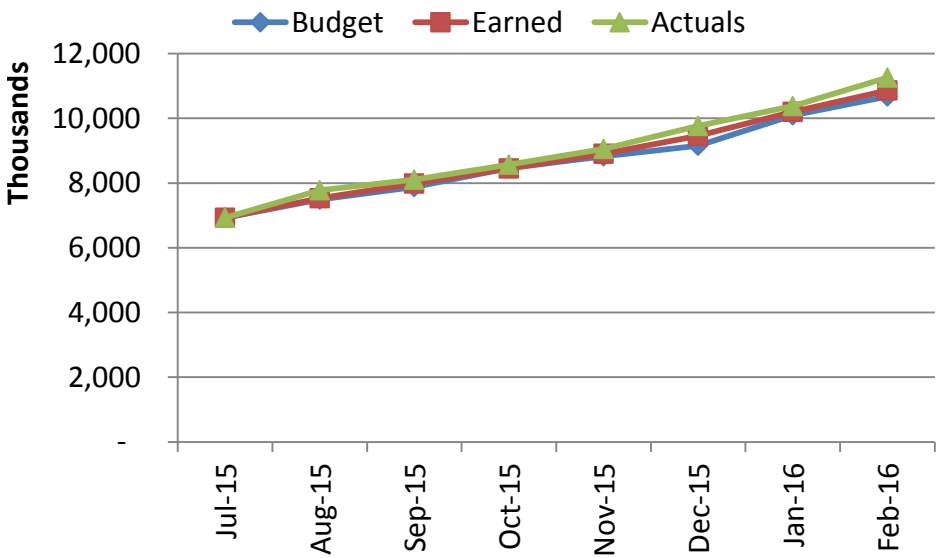
PWC and Ion Chamber Schedule

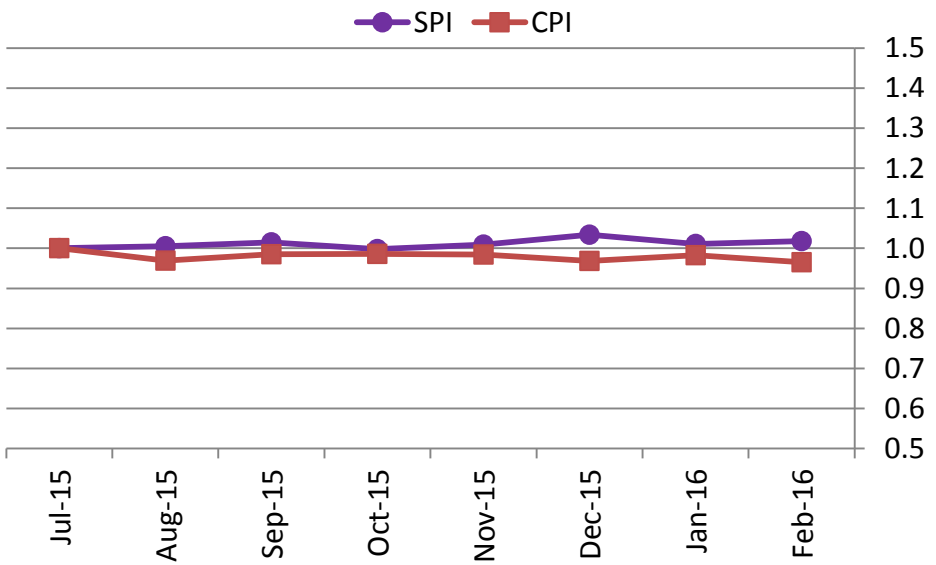


g-2 Accelerator Earned Value Management

EVMS

- Accelerator within 4% of budgeted cost for work completed
- Overall slightly ahead of schedule





EVMS

Control Account	Budget	Earned	Actuals	SV ($)	SV (%)	CV ($)	CV (%)	SPI	CPI	BAC	EAC	VAC	% Spent	% Complete
476.02.01 Accelerator Project Management	1,887,361	1,887,361	1,927,994	0	0%	(40,634)	-2%	1.00	0.98	2,589,640	2,630,273	(40,634)	73%	73%
476.02.02 Target Station	1,159,403	896,866	933,976	(262,537)	-23%	(37,110)	-4%	0.77	0.96	1,663,613	1,701,166	(37,553)	55%	54%
476.02.03 Beamlines	6,332,589	6,908,718	7,114,725	576,129	9%	(206,007)	-3%	1.09	0.97	12,103,524	12,303,762	(200,238)	58%	57%
476.02.04 Controls & Instrumentation	1,292,811	1,170,352	1,277,737	(122,459)	-9%	(107,385)	-9%	0.91	0.92	1,690,326	1,812,784	(122,459)	70%	69%

- Target Station: pulsed power supply procurements behind schedule but parts will be received in time for baseline assembly dates
- Controls & Instrumentation: (anti)vacuum chambers for PWCs and Ion Chambers behind schedule and over budget due to prototyping but further overruns not expected
  - Will be ready in time for baseline M4/M5 installation dates
  - Can give priority to ion chambers in M2/M3 and Delivery Ring

Accelerator Baseline Change Requests

BCR	Doc #	Change	Date Submitted	Date Approved	Accel PM	Target Station	Beam lines	Controls & Instrum
22	3123	Baseline (S=P=A)	25-Sep-15	9-Oct-15	-47,285	14,503	-204,109	-435,950
25	3181	Accelerator Lessons Learned	17-Sep-15	5-Nov-15	0	0	389,972	0
26	3214	Refinement of power supply procurement process	21-Oct-15	13-Nov-15	0	464	0	0
28	3252	Procure Wachs cutter & Fabrication of Trim PS	30-Oct-15	13-Nov-15	0	0	39,106	0
29	3253	FY16 Rate Change	5-Nov-15	17-Nov-15	2,082	-14,937	-121,248	-46,034
33	3408	PWC and IC (Anti)Vacuum Cans	14-Dec-15	6-Jan-16	0	0	0	133,591
35	3502	M4/M5, C-mag, Lambertson	13-Jan-16	16-Feb-16	0	0	406,807	0
37	3488	Blind Bolt Mitigation		16-Mar-16	0	0	132,913	0

- Actively managing changes to scope and schedule using BCRs

BCR025 and 035 – AIP Lessons Learned

- Addition of design/drafting and installation labor based on experience with the Beam Transport AIP
  - Specification drawings needed for procurements and installation drawings (previously assumed to be done in the design phase)
  - Oversight of installation
  - Correction for the number of mechanical techs assumed to be on a crew
- BCR025: M1 final focus/M2/M3 installation and procurement drawings for Delivery Ring and M4/M5
- BCR035: DR/M4/M5 installation
  - Separate, later BCR to better base our estimates on the M1/M2/M3 installation and not tie up contingency unnecessarily in case new estimates were too high
- BCR035 also revised schedule for magnets from Tech Div

BCR026 – Target Station Power Supply Procurement

- Refined schedule for procurement of parts for target station lens and momentum-selection magnet pulsed power supplies
- Broke up single activity “Procure parts” into 12 separate activities

BCR028 – Wachs Cutter

- Procure Wachs cutter used to cut beam pipe
- Available cutters were not suitable for large-diameter pipe

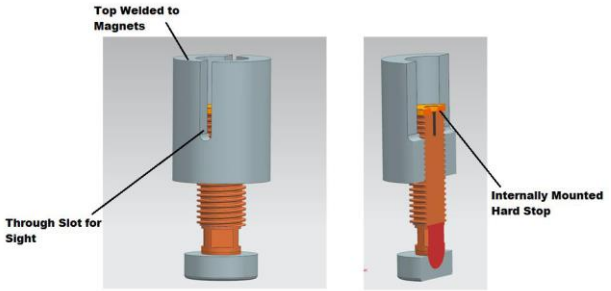
- Also split M4/M5 beamline power supply activities into separate activities for two different types of power supplies (no impact to cost)

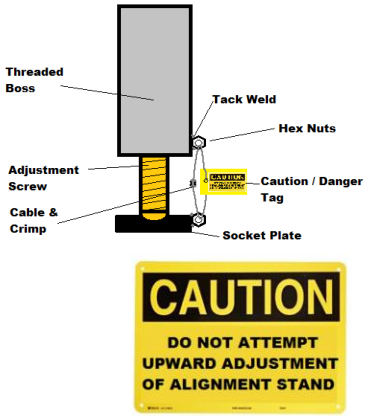
BCR033 – Anti-vacuum Chambers / Bayonet Cans

- Add electron beam welding of antivacuum cans to hold ion chambers and proportional wire chambers
- Re-machining of bayonet vacuum cans used for inserting the devices into beamline
- Needed to meet vacuum spec of 10^{-8} Torr
- Realization of risks 2416 and 2418 (estimated $65k-$135k)

BCR037 – Blind Bolts

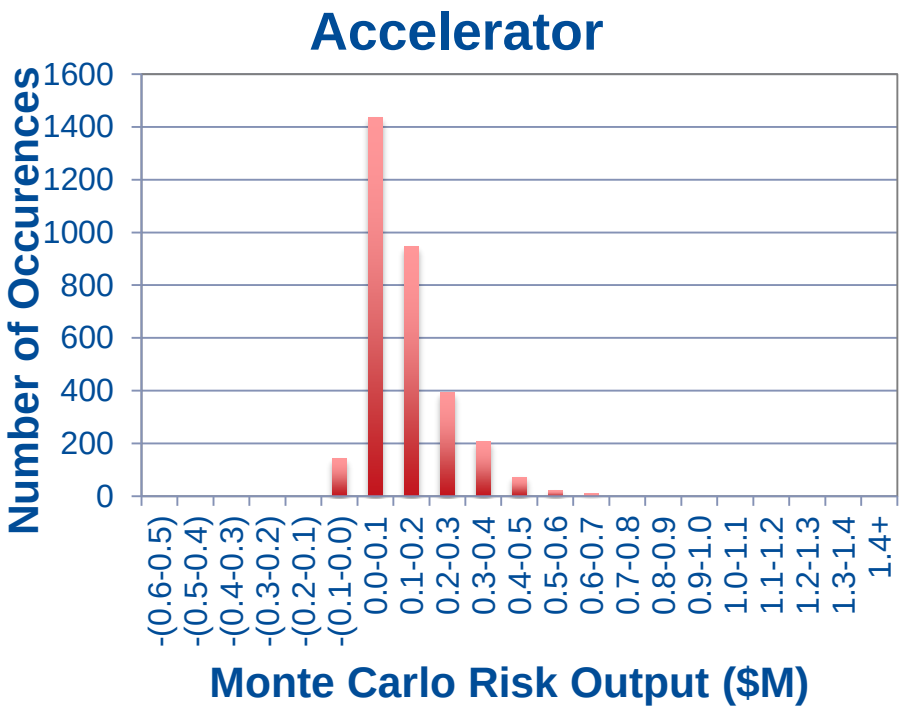
- The design of some stands was modelled after existing stands which unfortunately had a safety flaw
  - During alignment, bolts could be adjusted to the point that the magnet was no longer supported by the stand
  - The end of the bolt was not visible, so alignment experts could not tell when this point was reached
- We had already installed (but not aligned) several magnets in the M2/M3 line when we discovered this
- Committee (appointed at g-2 request) engineered fix
  - Modify stands of magnets touched during g-2 installation
  - Tag existing stands of magnets not being touched
- Redesigned M4/M5-line stands since they had not yet been sent out for procurement





Risk Registry

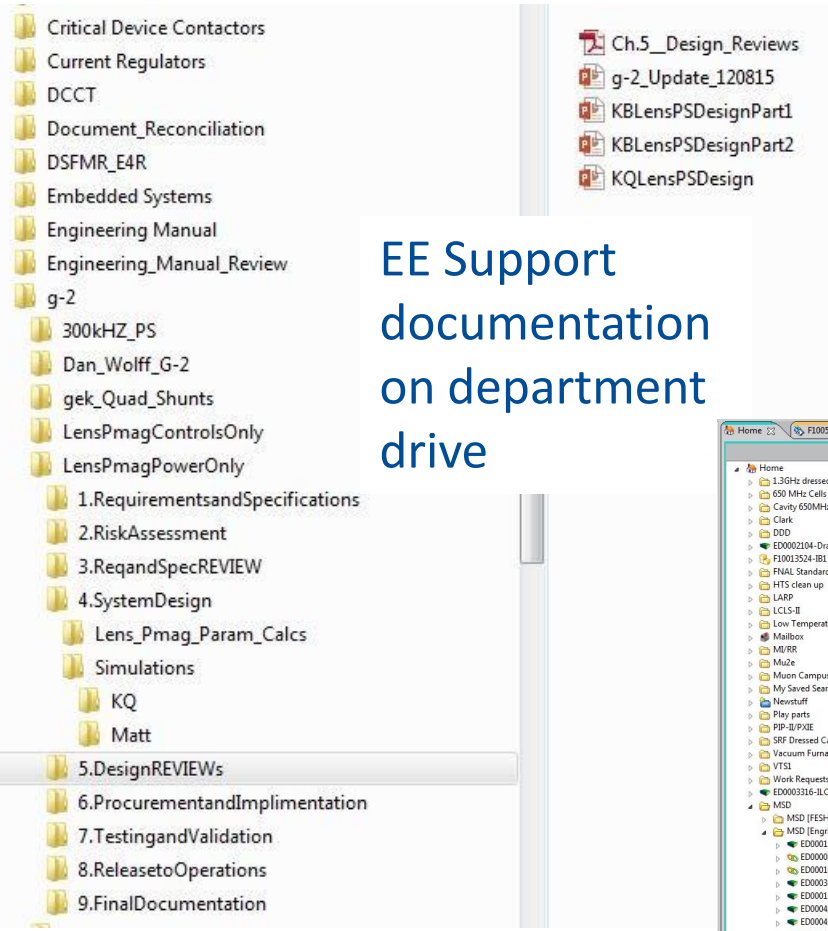
- 2 threats retired since CD-2/3
- 2 threats realized ($134k)
- No new risks added to registry
- Remaining 90% CL risk $0.3M
- Highest cost risks listed below
  - No high-severity risks remain
- Largest schedule risk is kicker power supply construction (limited number of experts)



Risk	WBS	Type	Description	Probability	Cost ($k)
2315	476.02.03	Threat	Kicker power supply may be more expensive or take longer	Low (10%-25%)	200
2417	476.02.04	Threat	Need to add low-intensity intensity measurement device	High (75%-90%)	80
2208	476.02.02	Threat	Additional cost for power supply parts due to pulse rate change	High (75%-90%)	50
2204	476.02.02	Threat	Complications in removal of dump	Low (10%-25%)	25

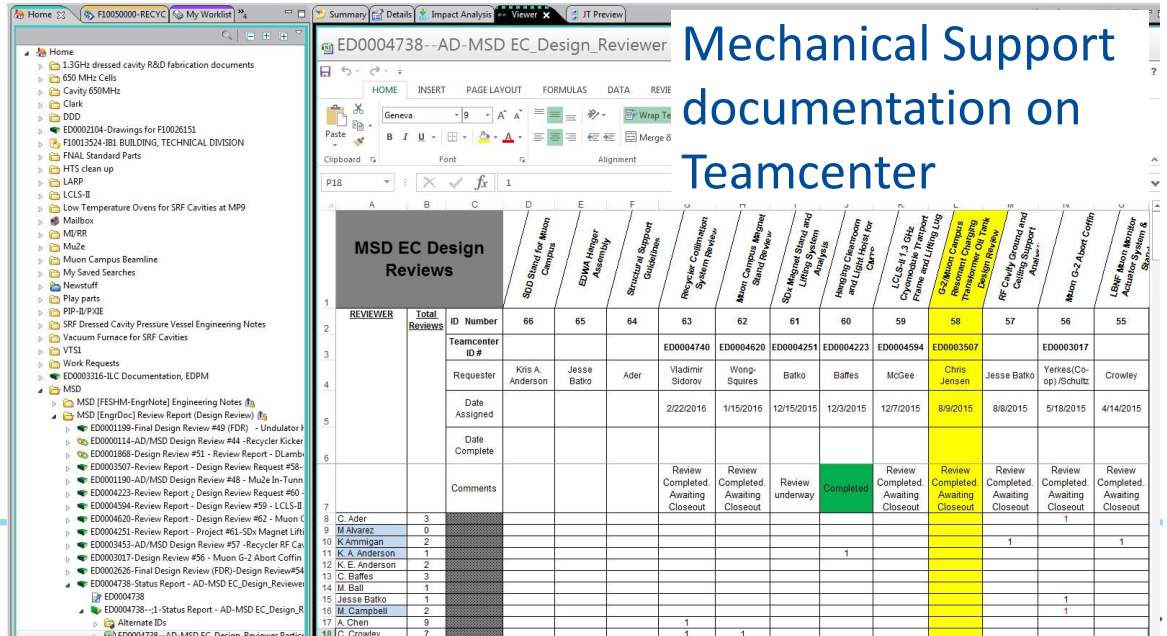
Follow-up from previous review

- "The Committee encouraged the project to formally capture design review results."



EE Support documentation on department drive

- The engineering support departments document engineering design reviews in accordance with the Fermilab Engineering Manual
- g-2 personnel have been made aware how to access these documents



Mechanical Support documentation on Teamcenter

Follow-up from previous review (cont.)

- "The beamline interface control document is now in place; it is a good start, the Committee would like to see more detail, namely beam position and angle could be captured along with tuning ranges and error bars. (The Committee believed this information exists.)"
  - gm2-doc 2739 has been updated

Follow-up from previous review (cont.)

- "The electron beam welding of the Ti window to ‘anti-vacuum’ aluminum chamber may not be trivial due to the difference in material properties. Earlier testing is recommended."
  - Done, see slide 35

Follow-up from previous review (cont.)

- Recommendation 1: "Regularly evaluate and take advantage of any opportunity to move up the completion of the pulsed magnet power supplies, including the extraction kicker, and test them in 100 Hz burst mode. Report on progress at independent project reviews."
  - No opportunity to advance schedule has yet occurred but on track to meet baseline complete date
  - Target Station pulsed power supplies have 5 months scheduled time to test 100 Hz burst mode plus 1 month float
  - Kicker power supply work has sufficient resources now that engineering design is complete
  - Recycler extraction kicker power supply (on Beam Transport AIP) has been tested in 100 Hz burst mode
    - Ran with 8 pulses in a burst of 100 Hz at full voltage for about 1 week at 4 Hz average
    - Working our way up to 12 Hz average

Beam Commissioning Plans (not on Project)

- First stage: beam to the target station dump
  - Aim for October 2016
  - Commission beam from the Recycler through the new extraction kicker and Lamberston, through the RR-to-P1 beamline connection, through the modified P1, P2, M1 lines to the new target station beam dump
    - Coordinated by AD Muon Dept; software, safety config in progress
    - Requires coordination with installation in the Delivery Ring
    - Need to limit distraction from g-2 installation (same experts)
  - Commission new Recycler RF with beam to the Recycler dump
    - Does not disrupt g-2 installation
- Detailed plan for commissioning the target station and g-2 beamlines was presented in CD-2/3 Followup Review breakout

Summary

- Accelerator work is 60% complete
- Work has been conducted safely
  - Modifications to stand design to correct potential safety issue
- Actively managing scope and schedule using EVMS
  - BCRs when appropriate
  - ETC updated monthly
  - No planned accelerator scope enhancements
- Risk analysis up to date
  - Remaining risks have low cost and schedule impact
- On schedule for completion at the end of March 2017